Comparison between two single-column models designed for short-term fog and low-clouds forecasting

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ABSTRACT:
There is a large impact of fog and low clouds in the field of airborne transportation. As a consequence, there is an increasing demand of precise forecasts in order to mitigate the negative effects of visibility reduction. Nevertheless, the production of these forecasts constitutes an unsolved issue yet. In several places, one-dimensional (single-column) models have been tested for local forecasts. They provide many insights into the complex physical mechanisms that are relevant in the fog or low clouds formation. Nevertheless, any influence related with surface or atmospheric horizontal unhomogeneity remains, in most cases, out of control.
In 2005, an intercomparison experiment among different single-column models in the field of fog and low clouds forecast was carried out. Since the results were useful but inconclusive, it was agreed to undertake a massive and systematic comparison between H1D and COBEL-ISBA. During the intercomparison period, the models have been run for Paris-Charles de Gaulle International Airport. The most significant difference between the models is found in the nocturnal cooling rate, which is -on average- stronger in H1D. The reason could lie in the fact that H1D predicts less cloud coverage than COBEL-ISBA.
The verification results show that the initialization is an important aspect for very short-term forecast and COBEL-ISBA seems to perform better for this point. They also demonstrate that the treatment of horizontal heterogeneities is important for longer forecast scopes, and H1D seems to perform better for this aspect.
Key words: atmospheric boundary layer, ceiling, fog, forecast, single-column model, visibility.

Comparación entre dos Modelos Unidimensionales Diseñados para Predicción a Corto Plazo de Niebla y Nubes Bajas

RESUMEN:
El impacto de la niebla y las nubes bajas en el transporte aéreo es muy importante. Existe una demanda creciente de predicciones precisas que permitan mitigar los efectos negativos de la reducción de la visibilidad. Sin embargo, la realización de estas predicciones constituye todavía un reto sin resolver. En varios lugares se han ensayado modelos unidimentales (de columna vertical) para predicciones locales. Estos modelos proporcionan mucha información sobre los complejos mecanismos físicos que intervienen en la formación de la niebla y las nubes bajas. Sin embargo, las influencias relacionadas con la inhomogeneidad horizontal de la superficie o de la atmósfera quedan, en la mayoría de los casos, fuera de control.
En 2005 se realizó un experimento consistente en comparar el comportamiento de distintos modelos unidimensales en la predicción de niebla y nubes bajas. Puesto que los resultados fueron útiles pero no concluyentes, se acordó llevar a cabo una comparación masiva y sistemática entre H1D y COBEL-

ISBA. Durante el período de comparación, los modelos han realizado predicciones para el aeropuerto internacional de París-Charles de Gaulle. La diferencia más significativa entre sus resultados se encuentra en el ritmo de enfriamiento nocturno, que en promedio es mayor para H1D. La causa podría residir en que H1D predice una menor cobertura nubosa que COBEL-ISBA.
Los resultados de la verificación muestran que la asimilación de datos es un aspecto muy importante para la predicción a muy corto plazo y COSBEL-ISBA parece comportarse mejor en este aspecto. También demuestran que el tratamiento de las inhomogeneidades horizontales es importante para plazos de predicción más largos y H1D parece comportarse mejor en este caso.
Palabras clave: capa límite atmosférica, techo de nubes, niebla, predicción, modelo unidimensional de columna, visibilidad.

1. INTRODUCTION

There is a large impact of fog and low clouds to personal safety and economy, especially in the field of airborne transportation (Allan et al., 2001). Adverse ceiling and visibility (C&V) conditions is a contributing factor in 35% of the weather related accidents in the civil-aviation sector and causes on average 168 fatal casualties per year (Herzegh et al., 2004). On the other hand, the flow of air traffic into major airport terminals is reduced by poor visibility conditions: fog is one of the major causes of aircraft delays. As a consequence, there is an increasing demand of precise forecasts that could mitigate the negative effects of visibility reduction. Its production becomes, then, a priority of the operational weather services: see e.g. US Northeast C&V Initiative (Tardif, 2002) or EU COST Action 722 (Michaelides, 2005).

A summary of the shortcomings of numerical weather prediction (NWP) models in providing the operational forecasters with suitable products for fog and low clouds prediction can be read in Bergot et al. (2005): The first problem of operational NWP models is the deficient parameterization of the exchanges both within the atmospheric boundary layer (ABL) and between the surface and the lowest layers of the ABL. These parameterizations are especially imprecise in the stable ABL, the atmospheric framework for the fog development (Viterbo et al, 1999; Holtslag, 2003). The life cycle of a fog layer (formation, vertical development and dissipation) is also directly related to microphysical processes that are not represented accurately enough in the models. Other problems of NWP models lie in their scarce horizontal and vertical resolutions, which are not suitable to predict phenomena, which sometimes fall well within the microscale domain. Moreover, models are usually committed to reject observations that are not representative of a relatively extended area or to modify them in order to improve their representativeness. In addition, during the assimilation process, the initial fields of mass and wind are forced to evolve in order to fulfil some prescribed, but not always realistic, relationships aimed to avoid the numerical growth of spurious waves. Therefore, especially over inhomogeneous terrain, the state of the atmosphere at a specific location can be considerably different to that in the closest model grid-point achieved after completing the initialisation procedures.

One way to overcome these problems is the use of one-dimensional (single-column) models (SCMs), where the terms depending on the horizontal structure of the atmosphere can be estimated from the outputs of operational three-dimensional

(3D) models. The application of SCMs for fog simulations provides many insights into the complex physical mechanisms that are relevant in the fog or low clouds formation. On the other hand, any influence related with surface or atmospheric horizontal unhomogeneity remains, in most cases, out of control. The SCMs have been operationally used in different places for fog and low clouds forecasting: (Teixeira and Miranda, 2001; Tardif, 2002; Bergot et al., 2005; Terradellas and Cano, 2007).

In 2005, an intercomparison experiment among different SCMs in the field of fog and low clouds forecast was carried out (Bergot et al, 2007). The results of six different models were analysed for two events documented during the fog field experiment performed by Météo-France / Centre National de Recherches Météorologiques (CNRM) at Paris-Charles de Gaulle International Airport (Paris-CdG) (Bergot et al., 2005). The intercomparison experiment has proved that SCMs can simulate the major features of the fog cycle. However, a high sensibility to the physical parameterisations and vertical resolution has been found. It revealed significant differences in the nocturnal cooling rate near the ground before the onset of fog, especially in the case of strongly stable stratification, when the parameterisation of boundary layer and surface exchanges is especially deficient. The intercomparison also demonstrated that the dew deposition rate and the gravitational settling flux are of a crucial importance in relation with the fog life cycle.

Since these results are useful but inconclusive, it was agreed to undertake a massive and systematic comparison between H1D (acronym of HIRLAM 1 Dimension) and COBEL-ISBA (acronym of *COde de Brouillard à l'Èchelle Locale* – Interaction between Soil, Biosphere and Atmosphere), SCMs that are respectively used at the *Instituto Nacional de Meteorología* (INM) and *Météo-France* for short-term C&V forecast. The main results of this experiment are described in the present paper.

2. THE MODELS: COBEL-ISBA AND H1D

2. 1. COBEL-ISBA

The COBEL boundary layer numerical model (Bergot and Guedalia, 1994) was first developed between the Laboratoire d'Aérologie / Centre National de la Recherche Scientifique (CNRS) and Météo-France / CNRM, in Toulouse, France. Its equations are solved on a high-resolution vertical grid with the first level at 50 cm above ground level (AGL).

The physical package includes a parameterisation of boundary layer turbulent mixing, cloud diagnosis and a scheme of radiative transfer. The vertical diffusion is parameterised using a prognostic equation for the turbulent kinetic energy (TKE) and a diagnosed mixing length, according to Estournel and Guedalia (1987) for stable conditions and to Bougeault and Lacarrière (1989) for unstable stratification. The longwave (LW) radiation scheme computes the fluxes for 232 spectral intervals between 4 and 100 μm (Vehil et al., 1989). The effect of the droplets is calculated through a linear relationship between optical depth and liquid water content (LWC). The shortwave (SW) radiation scheme computes the fluxes for the whole spectral interval, following Fouquart and Bonnel (1980). The optical thickness of the droplets is also calculated from the LWC. The condensation is parameterised assuming energy and total water conservation: after saturation, the excess of water is condensed. The gravitational settling of droplets follows Brown and Roach (1976). Finally, the visibility is diagnosed from the liquid water content (LWC), using the expression deduced by Kunkel (1984) after the analysis of several fog episodes.

The COBEL atmospheric model was coupled with the multilayer surface-vegetation-atmosphere transfer scheme ISBA-DF (Boone et al., 1999; Boone, 2000). The main advantage of the ISBA parameterization is that it is capable of accurately reproducing the energy and water budgets with a simple set of equations as confirmed by Henderson-Sellers et al. (1995), Chen et al. (1997) or Calvet et al. (1999).

2. 2. H1D

The H1D model is a single-column model developed at the Instituto Nacional de Meteorología (INM) from the HIRLAM limited-area model. It has a resolution that is currently set to 60 levels in the vertical and that increases towards surface. The lowest full level, where temperature, specific humidity and wind are defined, is located at about 30 meters above ground level (AGL). It is integrated with a time-step of 10 seconds. The physical package includes a tiled surface scheme, a turbulence parameterisation based on the TKE prognostic equation, a radiation scheme, a parameterisation of moist processes including large-scale and convective condensation and a parameterisation of visibility based on the LWC. The radiation scheme is based on Savijärvi (1990). Its first implementation in HIRLAM is documented in Sass et al. (1994) and later improvements in Wyser et al (1999). The scheme only considers two spectral parts: the solar or SW and the thermal or LW bands. The SW clean-air flux is obtained by reducing the top of the atmosphere flux by a broadband absorption depending on the LWC. In cloudy air, the SW flux is reduced by a total cloud transmissivity that takes into account the zenith angle and the cloud condensate amount. In the calculations of radiative fluxes at surface, the SW albedo is estimated from the surface type, solar zenith angle and snow cover. The LW scheme, based on Räisänen et al. (2000), explicitly considers the emissivity for water and CO_2, whereas other effects are added as extra terms. Cloud absorption is computed from the cloud condensate amount. LW surface emission is estimated from the surface type and the skin temperature. The turbulence scheme consists of a prognostic TKE equation with a diagnostic mixing length. It is based on the CBR scheme described in Cuxart et al. (2000), but with important modifications. The main change is the substitution of the original mixing length by a new formulation (Lenderink and de Rooy, 2000). The surface scheme uses the so-called mosaic of tiles approach (Avissar and Pielke, 1989). Such approach is especially important in SCMs because it is the only way to explicitly represent a horizontal heterogeneity. The surface fluxes of heat, moisture and momentum are independently calculated at every tile using the ISBA scheme (Noilhan and Planton, 1989; Noilhan and Mahfouf, 1996). Then, they are aggregated, so allowing an independent evolution of different land-use patches, which are only coupled through the atmosphere. Five different surface types are considered: sea or inland water, ice, bare land, low vegetation and high vegetation. The soil is represented by a multi-layer scheme with prognostic equations for temperature and moisture, except in water tiles, where the surface temperature is set to constant. STRACO, the parameterisation of moist processes, is based on a Kuo-type convection scheme (Kuo, 1974). It emphasises the gradual transitions between convective and stratiform regimes. The representation of microphysical processes follows Sundqvist (1993). The visibility is diagnosed following Kunkel (1984).

3. SITE AND INSTRUMENTATION

During the intercomparison experiment, the models were run for Paris-CdG. The airport is situated 20 km northeast from Paris, between agricultural lands and urbanised areas. The climate is oceanic, although the distance from the sea and the sporadic outbreak of continental air masses originate a relatively large thermal variation. The frequency of foggy days –radiative fog in most cases- is around 8%, with a maximum of occurrence around sunrise. Paris is located on the Seine Basin that, as most of the western and northern French territory, is a part of the European plain, with mostly flat terrain or gently rolling hills.

In addition to the standard aeronautical observation system, a number of specific instruments are deployed around the airport:

— A 30-m meteorological tower collecting observations of temperature and humidity in the surface boundary layer (at 1, 5, 10 and 30 m AGL)

— Shortwave and longwave radiometers, measuring upward and downward radiation at ground and at the roof of the airport terminal (at 45 m AGL)

— Soil temperature sensors at 5, 10, 20, 50 and 100 cm depth

— Soil humidity sensors at 5, 10, 20, 30 and 40 cm depth

More details on the observational set-up can be read in Bergot et al. (2005).

4. THE MODEL RUNS

The models are run following their respective standard operational set-ups, first for a test period lasting from 16 January to 14 February 2005, and then for a full winter season from 1 October 2005 to 28 February 2006.

COBEL-ISBA is run eight times daily, every three hours, for 12 hours during the test period and for 6-8 hours during the winter 2005-2006. It is associated with a specific assimilation system aimed to produce a physically consistent representation of the lower atmospheric and soil profiles. This system, widely described in Bergot et al. (2005), combines data from conventional and dedicated measurements with profiles, both from a previous COBEL-ISBA forecast and from ALADIN, the operational 3D model. The mesoscale forcing consists of the geostrophic wind and the cloud cover that are ingested from ALADIN every 3 hours and linearly interpolated with respect to time.

H1D is run four times daily for 24 hours. It is initialised from the HIRLAM analysis, a previous H1D forecast and the standard three-hourly observations, as described in Terradellas and Cano (2007, in press). The mesoscale forcing, consisting of horizontal advections, geostrophic wind, vertical velocity and surface pressure variations, is estimated from the 3D HIRLAM forecasts. Since the real runtime is three hours and several minutes after the nominal runtime, the HH+03 observation is already available. It is assimilated following a nudging scheme (Hoke and Anthes, 1976).

5. RESULTS AND DISCUSSION

5.1. ANALYSIS OF FORECAST DISPERSION

Low correlation between simultaneous forecasts of a magnitude issued by different models is a symptom of weak predictability of that magnitude. The dispersion obviously grows with the lead-time of the forecasts. Fig. 1 represents simultaneous predictions of different magnitudes. The lead-times range from 0 and 8 hours and are the same in all the panels. The forecasts of the basic magnitudes at screen level are reasonably similar: the correlation coefficients are 0.98 for temperature, 0.96 for specific humidity and 0.54 for wind speed. There is still a relatively good agreement between the forecasts of those magnitudes at 1000 m AGL. Nevertheless, the dispersion is very high for the liquid water forecasts: the integrated values up to 1 km AGL present a correlation coefficient of 0.32.

Such large divergence in the liquid water forecasts can be partially attributed to the parameterisation of boundary layer and surface exchanges, which, especially in a very stably stratified atmosphere, may present a very different behaviour. Sometimes, even slightly different nocturnal cooling or dew deposition rates may yield similar values for temperature or humidity, but important differences in the time when saturation is reached. In general, H1D predicts a larger amount of liquid water than COBEL-ISBA. In some cases, the LWC forecast by H1D close to ground (values up to 0.8 g/kg) seems too high for a classical fog layer. The parameterisation of moist processes, the gravitational settling in particular, can also produce important differences in the LWC.

Anyway, the large differences observed in the liquid water forecasts are evidence that quantitative forecast of fog, liquid water or, most generally, any phenomenon where liquid water is involved, is a very difficult task.

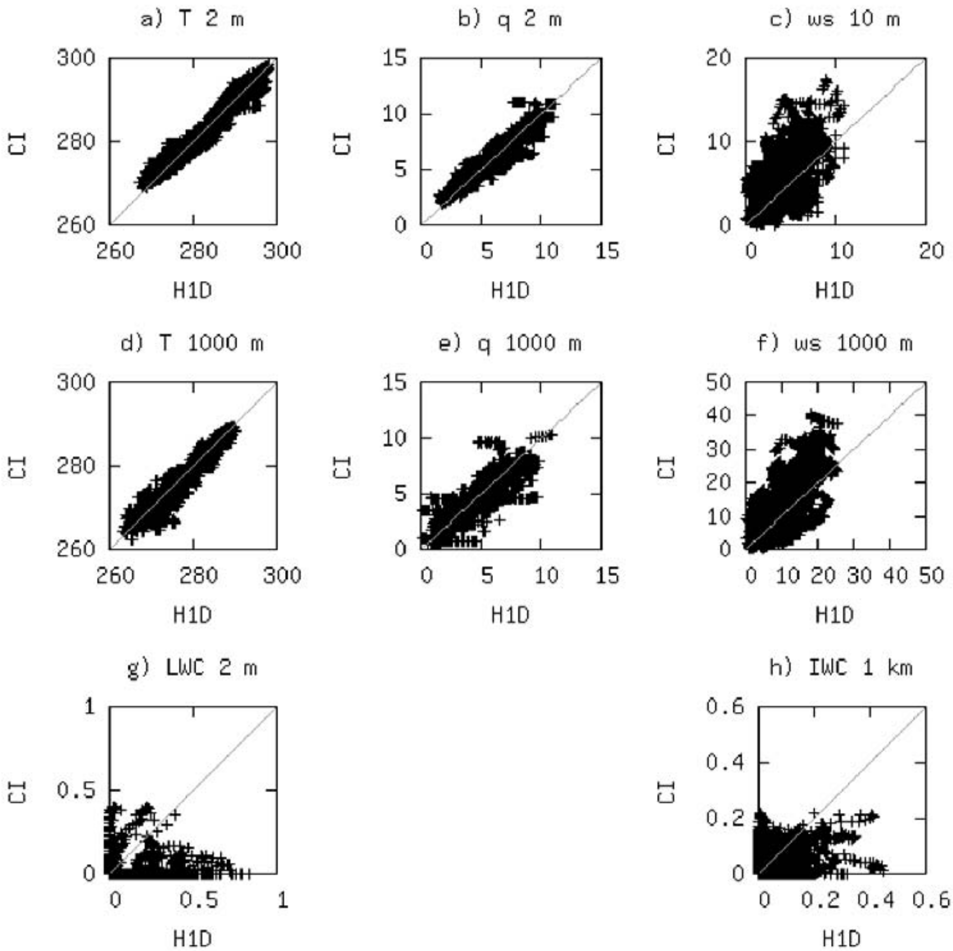

Figure 1.- Simultaneous predictions of different magnitudes issued by H1D and COBEL ISBA (CI) with lead-times ranging from 0 and 8 hours: a) screen-level temperature in K, b) screen-level specific humidity in gkg^{-1}, c) screen level wind speed in ms^{-1}, d) temperature at 1000 m AGL in K, e) specific humidity at 1000 m AGL in gkg^{-1}, f) wind speed at 1000 m AGL in ms^{-1}, g) liquid water content at 2 m AGL in gkg^{-1} and h) integrated liquid water content up to 1000 m AGL in gkg^{-1}.

5.2. COMPARISON OF THE FORECAST COLUMNS

The comparison between the forecasts issued by H1D and COBEL-ISBA for the lowest part of the column evidences that evolutions are similar. Both models predict, on average, similar humidity -only slightly higher in H1D- with the mean square difference growing, as expected, with time and height. The models also predict similar wind speed -slightly stronger in COBEL-ISBA- with the mean square difference growing with time and height. The most significant difference

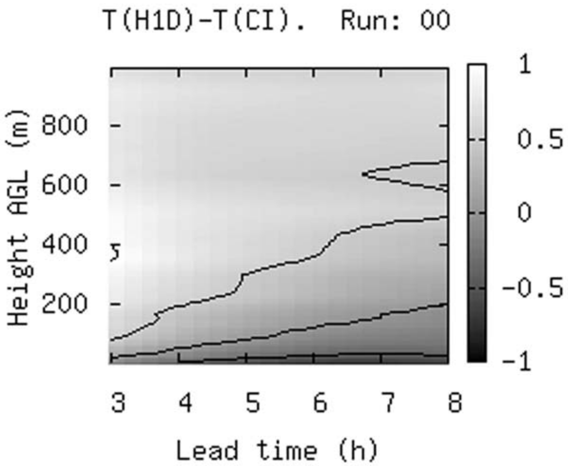

Figure 2.- Average difference between the vertical profile of temperature forecast by H1D and COBEL-ISBA in K in the runs started at 00 UTC.

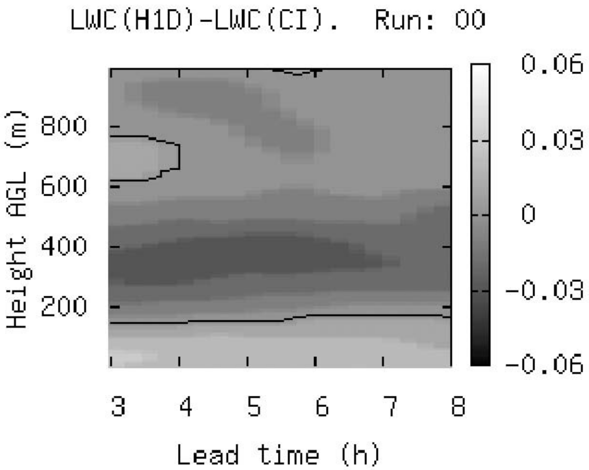

Figure 3.- Average difference between the vertical profile of liquid water forecast by H1D and COBEL-ISBA in gkg-1 in the runs started at 00 UTC.

between the models is found in the nocturnal cooling rate, which is -on average- stronger in H1D, as it can be noticed in Fig. 2. The reason could lie in the fact that H1D predicts less liquid water –less cloud coverage- than COBEL-ISBA between 200 and 600 m AGL (Fig. 3). Less cloud coverage implies more outgoing long-wave radiation (Fig. 4) and, therefore, a stronger radiative cooling. Lower nocturnal temperature would be the origin of a more frequent fog occurrence: Fig. 3 shows, below 200 m AGL, higher average liquid water content in H1D than in COBEL-ISBA.

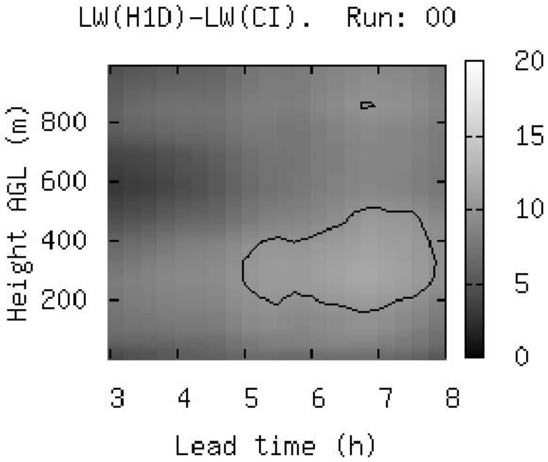

Figure 4.- Average difference between the outgoing long-wave radiation forecast by H1D and COBEL-ISBA in Wm^{-2} in the runs started at 00 UTC.

Some differences in the forecast columns cannot be attributed to the numerical model, but to initial data. An example is shown in Fig. 5, where, although low layers of the initial column (18 UTC) are considerably warmer in H1D than in COBEL-ISBA, both models present a similar evolution.

5.3. COMPARISON WITH NEAR-THE-GROUND OBSERVATIONS

The model forecasts of the basic magnitudes are now compared with observational data.

Since the initialisation window of H1D finishes at HH+03, the forecast scopes of this model have been shifted three hours in the comparisons: HH+06 in the simulation, for example, becomes a 3-hour forecast in the verification. The verification scores are, then, compared for the same real forecast scope, but not for the same hour.

Figs. 5 to 7 show the verification scores for the forecast of the basic magnitudes. The root mean square error (rmse) presents similar values for both models. Nevertheless, it is necessary to point out the already mentioned excessive cooling rate in H1D. A negative bias in the downward LW radiation at ground predicted by H1D (Fig. 8) reinforces the argument of an underestimation of the cloud coverage, but the final reason is not yet clear. It is suspected to occur in other sites located at relatively high latitude where H1D is run for (Warsaw and Cracow), but it has not been noticed in Spanish airports. On the other hand, a strong positive bias can be noticed in the wind speed forecast by COBEL-ISBA in the first hour. The origin of this bias seems to be in the initialisation.

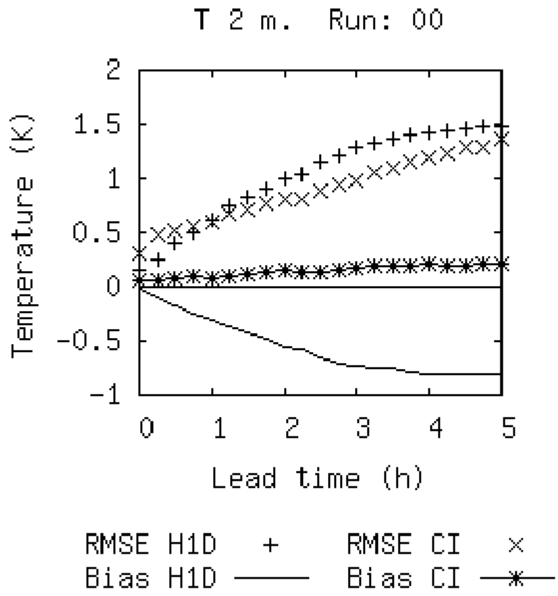

Figure 5.- Verification scores -bias and root mean square error- of the screen temperature forecasts issued by the 00-runs of H1D and COBEL-ISBA.

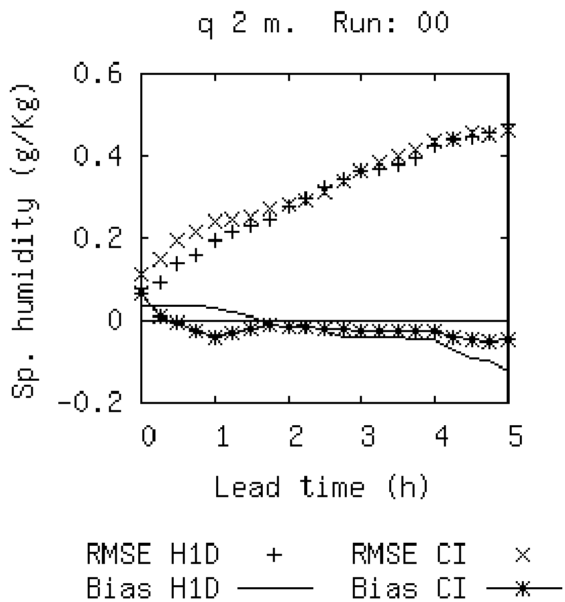

Figure 6.- Verification scores of the screen-level specific humidity forecasts issued by the 00-runs of H1D and COBEL-ISBA.

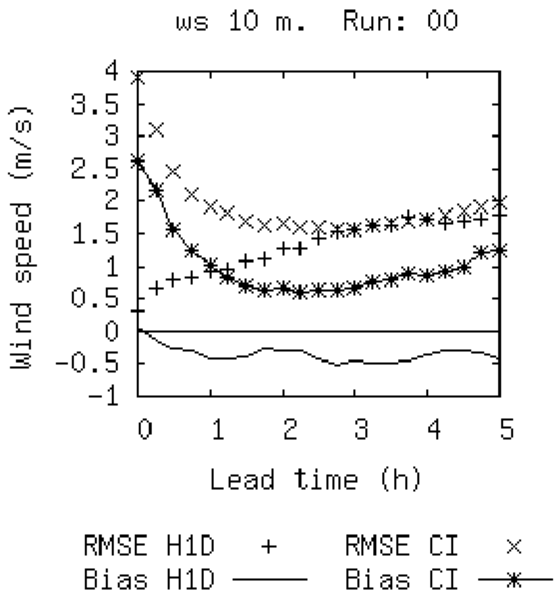

Figure 7.- Verification scores of the screen-level wind speed forecasts issued by the 00-runs of H1D and COBEL-ISBA.

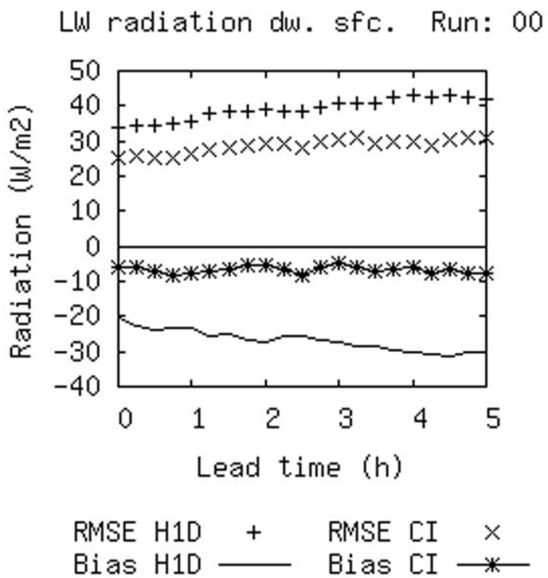

Figure 8.- Verification scores of the surface downward long-wave radiation forecasts issued by the 00-runs of H1D and COBEL-ISBA.

6. MODEL PERFORMANCE IN THE LOW C&V FORECAST

At Paris-CdG, low visibility procedures (LVP) are in force when visibility drops below 600 m or ceiling below 60m. Since the main objective of the development of the analysed models is the prediction of fog and low clouds, during the verification process, a special emphasis has been made to these thresholds. During the intercomparison period, C&V have been below LVP thresholds in 7.2% of observations.

For the H1D model, the verification has been made following the same criterion as in the previous Section. That is, the forecast scope has been considered from the end of the assimilation window.

Overall verification statistics are calculated based on binary LVP / no-LVP categories. The probability of detection (POD) is defined as the number of correctly forecast LVP cases divided by the number of LVP observations. The false alarm rate (FAR) is defined as the number of not observed, but forecast LVP cases (false alarms) divided by the number of forecast LVP cases. Finally, the true skill score (TSS) is the difference between them: TSS = POD – FAR.

Results point out a better performance of COBEL-ISBA for the shortest forecast scopes and a better performance of H1D for the longest forecast scopes. It would probably mean that H1D has a worse initialisation than COBEL-ISBA, but a better treatment of the horizontal heterogeneity, allowing relatively good scores for a longer period.

Tabla 1.- Verification of LVP conditions predicted by H1D and COBEL-ISBA for forecast scopes between 3 and 4 hours.

	H1D	**COBEL-ISBA**
POD	0.73	0.56
FAR	0.57	0.38
TSS	0.16	0.18

The verification results for a forecast scope between 3 and 4 hours are shown in Table 1. Both models present a similar performance, that is, a similar TSS value. The fact that H1D has a higher POD of LVP events, although at the price of a higher FAR, is, probably, the consequence of the excessive cooling rate mentioned above: lower temperatures originate more fog events in the simulations.

7. CONCLUSIONS

The *Instituto Nacional de Meteorología* (INM) and *Météo-France* have performed a massive and systematic comparison between the results of their respective SCMs for Paris-CdG during a whole winter season. The first conclusion is that SCMs, H1D and COBEL-ISBA in particular, are useful tools for local short-term C&V forecast. This comparison experiment has turned out to be an excellent tool in order to identify the weakest points of the models, the aspects where future work should focus on.

Results point out a better performance of COBEL-ISBA for the shortest forecast scopes and a better performance of H1D for the longest forecast scopes. The initialisation is a very important aspect and H1D developers should probably do more work on it, probably through the incorporation of dedicated observation systems and an adaptive assimilation scheme. The treatment of horizontal heterogeneity is a complex issue and it is a weak point in COBEL-ISBA. Moreover, this intercomparison also demonstrates that there is a large dispersion in liquid water forecasts that can be attributed to the weak predictability of magnitudes related to it. Anyway, values of TSS between 0.15 and 0.20 for the forecast of LVP events between 3 and 4 hours ahead justify the use of the models in the operational forecast.

This work has pointed out an excessive cooling rate in H1D forecasts: H1D seems to underestimate the cloud coverage in simulations at relatively high latitudes, but the cause is still unknown.

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